Comparing coeval plutonic and volcanic rocks in the Aleutian arc: Are primitive, mafic lavas representative of arc fluxes?

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Studies of geochemical cycling in subduction systems commonly assume that primitive basaltic magmas are representative of the compositional flux through the arc Moho, and/or of the bulk composition of arc crust. These assumptions are rarely tested. The Aleutian arc is unique among intra-oceanic arcs in its widespread exposure of Paleogene and Neogene, mid-crustal, felsic plutonic rocks, as well as their host lavas. Preliminary data suggest that many Aleutian plutonic rocks are derived from parental magmas that are geochemically distinct from typical basaltic lavas in the arc (Figure 1), perhaps because relatively hydrous magmas degas and stall in the mid-crust. If so, mafic lavas might not be representative of arc crustal bulk composition, or of net magmatic flux through the Moho into arcs. In order to evaluate this hypothesis, and a host of other fundamental questions, it is necessary to make a systematic comparison of the composition of coeval Aleutian plutonic and volcanic rocks.

Continental crust has been generated via geochemical processes similar to arc magmatism, perhaps followed by later reworking of arc crust. However, arc lavas worldwide are dominantly “mafic”, or basaltic, while continental crust is “felsic”, with an andesitic or dacitic bulk composition. Also, it is often inferred that bulk arc crust is mafic, on the basis of dominantly basaltic lavas, and high lower crustal seismic P-wave velocities in some arcs. As a consequence, petrogenetic processes have been proposed to produce felsic crust from a mafic protolith, including (1) formation of a felsic mid-crust via magmatic differentiation of basalt, followed by (1a) “delamination” of dense, mafic or ultramafic lower crust, or (1b) subduction and then “relamination” of buoyant, felsic mid-crustal rocks during subduction erosion and arc-arc collisions. Alternatively, (2) mid-crustal plutons, or entire arc sections, may be derived from mantle-derived andesitic magmas, rather than from the basaltic magmas common among lavas.

Notably, recent seismic data on the Izu-Bonin-Mariana (IBM) arc, together with reconstructed arc seismic sections for the Jurassic Talkeetna arc and the Jurassic-Cretaceous Kohistan arc, all suggest that these intra-oceanic arcs have a relatively felsic bulk composition, at least above the seismic Moho. Perhaps (as in hypothesis 1), all three arcs underwent substantial modification by delamination, or (as in 2) voluminous, early arc magmatism included a large proportion of primitive andesite. And, in the case of IBM, perhaps mafic to ultramafic cumulates are still present below the Moho. Seismic velocities for Aleutian lower crust appear to be higher than for IBM, but interpretation of these data is complicated by the unusual nature of the two arc crossings, and the oblique fore-arc to arc geometry of the one strike line. In any case, our focus here is on the plutonic middle crust.

Systematic study of coeval felsic and mafic rocks in an intra-oceanic arc could provide the essential information needed to unravel these different hypotheses. For example, (1) suggests that there should be no systematic difference in radiogenic isotope ratios between felsic mid-crustal plutons and coeval mafic lavas, since both are derived from the same mantle source. Alternatively, systematic differences between felsic plutons and mafic lavas would support hypothesis (2). This is crucial, since (2) suggests that primitive basalts are not representative of the net magmatic flux through the Moho to form arc crust.

Furthermore, understanding the genesis of felsic plutons that are coeval with dominantly basaltic lavas can provide fundamental insight into the processes of arc crustal accretion, regardless of whether felsic plutons are differentiated from typical arc basalts or not. In one view, high temperature, low-H_2O mafic melts with low viscosity erupt readily, whereas lower temperature, higher-H_2O felsic magmas undergo degassing in the mid-crust, and become too viscous to ascend further. In order to understand arc magmatism, it is essential to test this hypothesis, and quantify the nature of any systematic bias arising from such physical processes. For example, studies of H_2O-contents in melt inclusions in lavas might not yield an unbiased estimate of H_2O contents in the magmas that form plutons.

Throughout most intra-oceanic arcs, felsic mid-crustal rocks are not exposed at all. The Miocene, tonalitic Tanzawa plutonic complex in Japan is inferred to be tectonically exposed, felsic mid-crust from the IBM arc. However, it is geochemically distinct from continental crust (e.g., Tanzawa is depleted in K and light REE, whereas CC is enriched), and lacks spatial and temporal context with the rest of the arc.

In contrast, the Aleutian chain has characteristics that make it ideal for a study of plutonic rocks in an intra-oceanic arc. (A) The Aleutians have never been rifted, and still contain strata recording ~ 40 Ma of arc history. (B) Some primitive lavas have Nd, Sr, Pb and Hf isotope ratios indicating a depleted upper mantle source, similar to the MORB source. These are the isotopically depleted end-member among arc lavas worldwide. They are dominated by juvenile igneous material, rather than recycled components from continental crust and terrigenous sediments. (C) Despite their lack of recycled, older continental material, these same primitive Aleutian lavas have compositions almost identical to bulk continental crust, more so than in any other intra-oceanic arc. Formation of juvenile igneous rocks with the composition of continental crust is occurring in the Aleutians today. (D) Intrusive rocks – predominantly quartz diorite to granodiorite – are exposed on many of the larger islands together with their host volcanic rocks. The widespread presence of exposed intrusions in the Aleutians provides an unmatched opportunity for direct study of mid-crustal plutonic rocks, and their relationship to coeval volcanics.

We propose an extensive study of Paleogene and Neogene plutonic rocks and coeval volcanic rocks, together with volcanoclastic rocks in the Aleutians. We need to compare samples from the same island that have similar ages, so an important secondary outcome of our study will be extensive data on the geochemical evolution of the arc over time. Volcanic and plutonic samples will undergo zircon and $^{40}Ar/^{39}Ar$ geochronology, XRF and ICP-MS geochemistry, and radiogenic isotope analyses, and we will undertake geochemical and detrital zircon studies on volcanoclastic rocks.

Preliminary analytical work can be done on existing samples from [a] relatively detailed studies (Captains Bay pluton, Unalaska Island; Hidden Bay and Finger Bay plutons, Adak I.; Kagalaska pluton, Kalalaska I.), [b] reconnaissance mapping (large plutons other than Captains Bay on Unalaska I., southern parts of Atka I., Umnak I., Amchitka I., Attu I., Amlia I., Komandorksy Is.), and [c] dredging and submersible studies south of Adak and Kiska I. These will provide ages – including ages of detrital zircons in volcanoclastic rocks – to extend previous $^{40}Ar/^{39}Ar$ work, and geochemical data for initial constraints on the extent of isotopic variability within and between plutonic and volcanic suites.

Following these initial studies, we propose to conduct field work on several islands containing a variety of plutons of varying ages, together with their older volcanic host rocks and younger, overlying volcanics. Because Adak is relatively well-studied, the best targets seem to be the southern part of Atka, where excellent reconnaissance mapping suggests great potential, and the relatively accessible plutonic rocks on Unalaska and Umnak. Away from Unalaska, outcrops are mainly on sea cliffs along the shore. Depending on the level of funding, this field work can be conducted via Zodiak, or – preferably – with helicopter support from a research vessel such as the Maritime Maid (http://www.maritimehelicopters.com/).

To expand our spatial and temporal coverage, we will propose separate dredging and/or submersible studies of steep topography in the fore-arc. (The oldest known sample from the Aleutian arc is a plutonic rock from Murray Canyon, south of Kiska I). And, we will seek continuing collaborations with Russian colleagues to continue studies of Paleocene to Eocene volcanoclastic arc rocks (Aleutian? pre-Aleutian?) in the Komandorsky Islands, with the understanding that we would be happy to assist in sample analyses.

Our study will provide crucial information on mid-crustal rock compositions, together with the extent of fracturing and metamorphism, which can be used in interpreting existing and proposed, new seismic data on the Aleutian arc. Similarly, our petrological studies will provide constraints on the nature of deeper plutonic rocks in the middle and lower crust, which can be compared to inferences from seismic investigations in a dialectical process that will refine our understanding of arc lower crust.

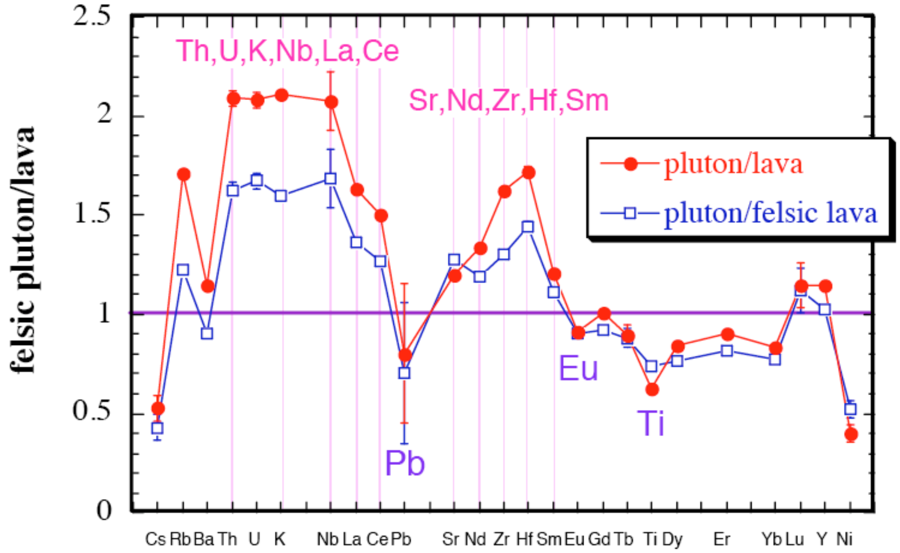

Figure 1: Average Aleutian felsic plutons (> 55 wt% SiO_2) compared to average lavas and average felsic lavas (> 55 wt% SiO_2). See Kelemen et al., AGU Monograph, 2003 and Treatise on Geochemistry, 2003 for data sources. Felsic plutons are enriched in some incompatible elements, compared to lavas, indicating that the plutons probably represent liquid compositions. The large difference at the same SiO_2 (and at the same molar Mg/(Mg+Fe) or Mg#, not shown) suggests that the plutons were not derived by crystal fractionation from the same parental magma composition as the lavas. Either (1) mixing of evolved and primitive compositions was systematically more important in forming the plutons, or (2) the plutons had a parental melt that was systematically different from the parent for the lavas. The data summarized here are mainly for Holocene lavas and Miocene plutons, so it is not yet clear whether the differences reflect spatial or temporal variation in magmatic processes.

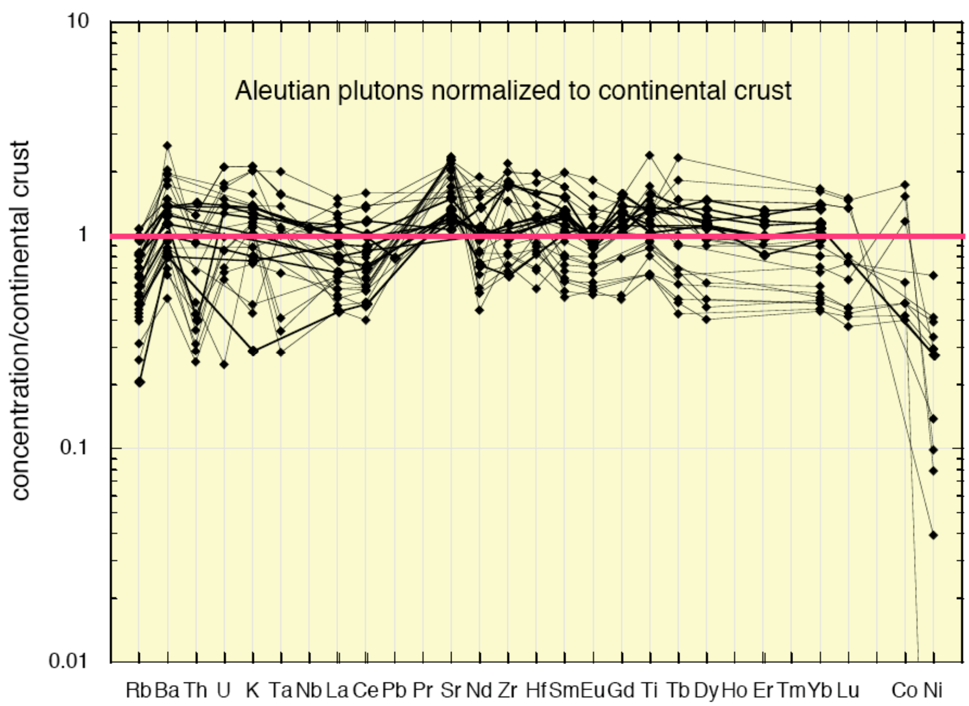

Figure 2: Comparison of average composition for Aleutian felsic plutons (> 55 wt% SiO_2; compilation in Kelemen et al., 2003) with bulk continental crust (Rudnick & Gao, Treatise on Geochemistry, 2003).